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SUBJECT: Viking Spacecraft for
Lunar Exploration
Case 340

DATE: June 30, 1970

FROM: R. N. Kostoff
M. Liwshitz
S. Shapiro
W. R. Sill
A. C. E. Sinclair

ABSTRACT

Six classes of lunar missions are described that use Viking spacecraft to bridge the gap between termination of the Apollo program in the early 70's and prospective resumption of manned lunar exploration in the 80's. The requirement for minimum modifications is met for these missions by excluding new instrument developments and by limiting changes in the propulsive system to those necessitated by descent on the atmosphereless moon. The missions described include orbital missions, using the Viking orbiter alone, as well as combined orbiter-lander missions. The former could meet the scientific objective of complete photographic coverage of the moon at high resolution ($\sim 10m$), or fulfill the operational need for partial coverage at even higher resolution ($\sim 2m$), desired for landing site survey. In the more ambitious scientific missions to regions near the pole, on the limbs, and on the far-side the primary experimental tasks would be performed on a suitably adapted lander, whereas the orbiter would function chiefly as a data relay. For the observation of transient events, one of the most intriguing lunar scientific problems, the experimental payloads of both orbiter and lander are essential.

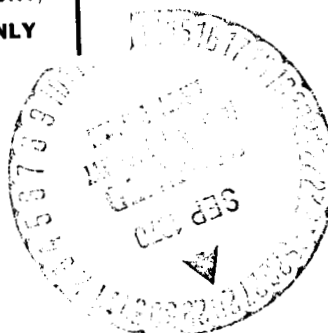
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(NASA-CR-113378) VIKING SPACECRAFT FOR
LUNAR EXPLORATION (Bellcomm, Inc.) 30 p

N79-72184

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12796

FF No. 60	1122	31
	(NASA CR OR TM OR AD NUMBER)	(CATEGORY)
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MEMORANDUM FOR FILE

1. Introduction

Figure 1 presents NASA's lunar and planetary program for the next twelve years. The Figure indicates that NASA's exploration of the moon in this decade will cease with the completion of the Apollo program in the early 1970's. The 1969 STG report envisions continuation of lunar exploration in the 1980's, by the use of a Lunar Orbiting Space Station and a Lunar Surface Base, which entail further manned landings on the moon.

A prolonged gap in the lunar program is thus apparent: during a period of at least six years no visits to the moon, manned or unmanned, are currently planned. This break, however, is undesirable for a variety of reasons, related to the objectives and orderly operation of the space program, as discussed in Section 2. In the present budgetary climate obviously no new costly manned lunar program for the 70's is conceivable, even if its timely technical implementation were feasible. Likewise, start of an independent new large-scale unmanned program appears to be beyond the available means.

On the other hand, NASA's program includes substantial work on the Viking Program during the period of the mid-70's. The present report suggests that an unmanned lunar exploration program may fit into the framework of the ongoing Viking program, drawing both on its hardware and other technical resources. In this fashion continuation of lunar exploration may be achieved at moderate cost, if modifications to the Viking system are held to a minimum.

While not addressing in detail their engineering design, this report describes in Section 4 six classes of lunar missions for Viking. The postponement of the first Martian Viking flights from 1973 to 1975 provides additional time to consider the lunar missions described, or similar ones, in planning for Viking.

2. Objectives for Lunar Viking

It is the general objective of the lunar program to develop an understanding of the origin and history of the moon from investigations of lunar composition, structures, age and processes. Another, specific, objective is to determine the extent to which the moon could be used as a base for further space exploration, for astronomical observations, or as a facility for exploitation of lunar resources, should any be discovered. Major activities in meeting these objectives are investigations of the thickness of debris, subsurface stratification, compositional analysis, thermal balance, thermal inertia, electrical properties, magnetic properties, the radiation and plasma environment and the gravitational anomalies.

With the completion of the Apollo program we shall have detailed studies of a number of carefully selected sites, with samples giving the composition and age of the materials at each site. Because of material transfer by meteor impact we may also expect to acquire samples originally from regions widely separated from the actual sites of acquisition. The subsurface character and the environment of the sites will be investigated by seismic experiments deployed by the astronauts. In addition instrument packages located in the CSM will, from 100 km altitude, remotely measure lunar surface topography, composition and environment, establishing the scale of lunar differentiation.

The shortcomings of the Apollo program arise from the limited number of sites to be visited. In particular, many important sites will not be visited, such as polar, far-side, limb and difficult front side regions. No long traverses will be made, and not more than six geophysical observatories will be emplaced. Thus, likewise, the areal coverage provided by the CSM experiments will be limited to a narrow band near the equator, with only a limited range of sun angles obtained for a given site. Only coarse spatial resolution will be provided by the electromagnetic and particle detectors.

Also, as has occurred in the case of the lunar magnetic field, it is likely that in the course of the Apollo program specific questions will arise that prescribe further studies, which, distinct from the above example, cannot be accommodated within the program.

It is also inconceivable that the high level of scientific capability and broad range of involvement in lunar studies of scientists from diverse disciplines and many nations could survive a complete cessation of lunar exploration for a protracted period.

Thus the principal objectives of a lunar Viking program will be

- a) to extend lunar exploration and to cover areas uncharted by Apollo;
- b) to provide data relevant to site selection for a lunar base;
- c) to answer specific questions raised by Apollo investigations;
- d) to maintain lunar scientific capability and involvement after the completion of Apollo.

3. Martian Viking Capability

This section gives a brief account of the major components of the Martian Viking system, including some general comments on their adaptability for lunar exploration. Further details that apply to specific missions will be discussed in Section 4. As will become apparent in the following considerations, the present Viking propulsion and communication systems provide excess capability for most lunar missions, while the experiment payloads of both orbiter and lander are not ideally matched to the required tasks.

a) Launch Vehicle and System Configuration

Figure 2 is a schematic of the Viking launch vehicle, the Titan III D/Centaur, and a Martian Viking payload. There are four main elements in this system, namely:

- 1) Solid rocket stage
- 2) Two stage core vehicle
- 3) Centaur stage
- 4) Payload compartment

The solid rocket stage, which consists of two strap-on five-segment solid rockets, is the zeroth propulsive stage. It provides 2.5 million pounds thrust for a two minute burn time. The Titan III core vehicle contains the liquid fueled stages 1 and 2. Stage 1 provides 500,000 lbs thrust for 2.5 minutes; stage 2 provides 100,000 lbs for 3.5 minutes. The Centaur, or upper, stage is liquid fueled and provides 30,000 lbs thrust for 7 minutes.

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Table 1

Lunar Viking Weight Breakdown

	lb	lb
Martian Viking Lander, without Aeroshell		
Body, without tanks	910	
Liquid rocket motor and tanks	70	1250
Liquid fuel	270	
Additional Solid Rocket Motor for Lunar Landing		
Body and tanks	200	1350
Fuel, descent from 100 km	1150	
Nominal Viking Orbiter		
Body without tanks	1425	
Liquid rocket motor & tanks	485	3850
Liquid fuel requirement, deboost to 100 km	1950	
(Liquid fuel capacity	2784)	
Orbiter-Lander Connector		<u>135</u>
Required in TLI		6585 lb
Available for TLI from Titan III D/Centaur		12,500 lb

Figure 3 presents a detailed view of the payload compartment housing the Martian Viking payload, and tabulates the system weights used as a basis for this study.

Table 1 gives the spacecraft weight breakdown for translunar injection (TLI) of the nominal Viking orbiter and lander. The latter is modified for retro-propulsive descent, which must replace aerobraking used for descent on Mars. Evidently the Titan III D/Centaur provides excess capability, and the orbiter fuel tanks provide excess capacity for a nominal mission. The latter is defined as a mission that puts the unmodified Martian orbiter into lunar orbit and emplaces on the surface the Martian lander, adapted as above for lunar descent; no other modifications or maneuvers are included.

As Section 4 and Appendix A will illustrate, alternative existing launch vehicles, such as the Titan III C or the SLV-3C or Atlas Centaur, may meet the requirements of specific lunar missions. The Titan III C, replacing the Centaur by a smaller transtage motor, can place 5,500 lbs, in TLI. SLV-3C with a TLI capacity of 3,000 lbs may be sufficient for an orbiter-only mission.

b) Orbiter Configuration and Instrumentation

The orbiter is an extension of the Mariner series of spacecraft. The spacecraft orientation is fixed in space with lock to the sun and Canopus. Roll about the sun line and pitch from the sun line are possible, with the orientation then held by gyros. Thermal control sets a limit of about 30° to pitch attitude.

The design lifetime of the system includes 6 months in the cruise phase with 3 months operation at Mars. For comparably long lunar missions, with their different division of the spacecraft's lifetime between the cruise and orbital phases, problems that may arise from additional solar occultation, thermal cycling and battery recharging need to be examined.

Instruments are mounted on a scan platform which permits viewing at angles from 15° to 84° from the antisolar direction. These limits may however, be extended during the course of program implementation.

The following brief listing of orbiter instrumentation includes relevant technical details of the TV and IR experiments, since these appear to be useful for lunar missions.

(i) TV System

2 identical boresighted cameras of 1050 mm focal length
Field of View: $1^\circ \times 1^\circ$ (~ 17 km x 17 km at 1000 km)
Number of resolution elements/line (pixels): 1152
Number of lines per frame: 1152
Size resolution element at 1000 km: 15m x 15m
Frame rate: 2.24 sec each camera, 1.12 sec for dual camera system
Bits/frame: 10^7 (at 7 bits/pixel)
Exposure time: from fractions of msec to a few msec
Weight: 35 lbs
Total power consumption: 60 w

(ii) IR Thermal Mapper

Field of View: $2.4^\circ \times 2.4^\circ$
Size of resolution elements: 6 km at 1000 km
Spectral range: 0.2-35 μ , five bands plus integral
Sensitivity at 200°K, 1 sec integrations: 0.85-0.17°K
Weight: 17 lb
Power: 10-12 w

(iii) IR Spectrometer

Field of View: 1.7° scan perpendicular to track
Size of resolution element at 1000 km: 1.8 km x 7 km
Sensitivity (for water): 1 μ precipitable H₂O,
corresponding to 10^{18} molecules/cm² in the line
of sight
Weight: 21 lb
Power: 4 w

c) The Lander Scientific Payload

Table 2 provides a short summary of the entire Martian Lander scientific payload

Table 2 - 1975 Viking Lander Payload for Mars

Instrument	Objective
Growth and Photosynthesis Detector	Life
Gas Chromatograph/Mass Spectrometer	Life/Atmosphere/ Surface
Anemometer, Pressure and Temperature Sensors	Atmosphere
UV Photometer	Atmosphere
Scanning Calorimeter	H ₂ O in Soil
Seismometer	Solid Body
Facsimile Camera	Surface/Atmosphere
Sampler Arm and Scoop	Surface
Radar and Radio Link	Atmosphere/Gravity

Evidently this Martian instrument package is strongly weighted toward life detection and atmospheric experimentation, whence many of its components are not suitable for lunar exploration. Some instruments may, however, with minor modifications be useful for a lunar Viking mission.

(i) Surface Sampler System

In the absence of striking dissimilarities between the lunar and Martian surface this system is of obvious use for the collection of lunar surface samples.

(ii) Gas Chromatograph/Mass Spectrometer

The multiple purpose and corresponding range of the Martian lander instrument provide for its utility in both chemical analysis of surface samples and detection of the, at best, tenuous lunar atmosphere, lunar outgassing and frozen volatiles.

(iii) Facsimile Camera

The present design of the facsimile camera calls for the acquisition of a $50^\circ \times 360^\circ$ panoramic view within ~ 9 hours. This long scan time is, however, predicated on the low data transmission rate available at Mars. Minor modifications of the camera's driving mechanism, not posing a costly problem, could result in the reduction of time to ~ 1 hour. This would enable the orbiter to receive in real time, over a period of ~ 15 minutes, a useful $90^\circ \times 50^\circ$ picture from a lander that cannot directly communicate with earth.

(iv) Seismometer

The proposed seismometer for Mars has a detection limit of 50 nm, compared to 1 nm of the present ALSEP instrument, and its design calls for mounting to the body of the lander rather than for direct emplacement on the planet surface. Since the signals recorded so far by the ALSEP seismometer typically have amplitudes of a few nm, the unaltered Viking instrument is limited to the detection of very large lunar seismic events.

d) Data Storage and Communication

The communication and data handling capabilities of the Viking System at 2.64×10^8 km range from earth are summarized in Table 3.

Table 3 - Viking Communication and Data System

Transmission rate (bps) lander-earth	10^3
Transmission rate (bps) lander-orbiter	$4 \times 10^3, 16 \times 10^3$
Transmission rate (bps) orbiter-earth	16×10^3
Orbiter record rate (bps) for own data	2.2×10^6
Orbiter storage capacity (bits) for lander data	8×10^7
Orbiter storage capacity (bits) for own data	5.6×10^8
Orbiter ground command reception rate (bps)	4×10^3
Lander ground command reception rate (bps)	4

In the current design, no provision is made for command relay via orbiter to the lander.

Using the same transmission power as used for the Martian mission and the same antennae on orbiter, lander and earth, the data rate from the moon could be increased by a factor of $\sim 7.5 \times 10^4$ over that obtained at maximal earth-Mars distance.*

4. Lunar Missions for Viking

a) General Considerations

From the many missions that can be considered suitable for Viking we describe six. These six have been chosen to demonstrate the breadth of Viking's capability for lunar exploration, in the light of the objectives described in Section 2, rather than to imply recommendations for priorities or for implementation of a lunar Viking program. In choosing these missions, we have required that modifications to the existing Viking system be held to a minimum, in order to minimize impact on cost and scheduling.

* For a given antenna system and fixed transmitted power in unit bandwidth, the received signal power/unit bandwidth varies as the inverse square spacecraft distance, r . In reception from a spacecraft near Mars ($r = 2.84 \times 10^8$ km), the noise power/unit bandwidth is proportional to the receiver system temperature, ($\sim 25^\circ\text{K}$ for Goldstone). In observing the spacecraft near the bright lunar disk ($r = 3.85 \times 10^5$ km) that fills the antenna beam, the receiver system noise temperature rises to $\sim 180^\circ\text{K}$, on the assumption of $\sim 300^\circ\text{K}$ effective lunar temperature and 60% dish efficiency. This provides for an increase in the signal-to-noise ratio P/N by a factor of 7.5×10^4 since the transmission capacity C is given by

$$C = W \log_2 (1 + P/N)$$

The enhanced ratio P/N is not too effective in increasing C , nor is it necessary. Rather the available power should be used for expanding the bandwidth, directly proportional to transmission capacity, by the factor 7.5×10^4 , while holding the signal-to-noise ratio at its fixed value.

b) Orbital Survey Mission

The objective of this mission is to extend the photographic coverage of the Moon provided by Orbiter and Apollo and to obtain an IR map of the moon.

As demonstrated in Appendix B, the Viking orbiter, with its unmodified camera system, travelling for one month at 460 km altitude in a circular polar orbit could provide a complete photographic map of the moon at a resolution of 8 m. The detailed ground truth knowledge gained from the Apollo sites would be used in the interpretation of the photographs. In this way, our understanding of the physical processes that have shaped the lunar surface and are manifest at the visual scale indicated, will be extended beyond the Apollo sites over the whole moon, including the far-side.

Alternatively full coverage at less detail is feasible in even shorter time, and one month would suffice for complete stereo coverage of the moon at 12 m resolution. On the other hand, complete coverage at better than 6 m resolution, requiring two months, appears to be precluded by the lack of overlap between adjacent ground tracks.

A further potential use of the orbiter is the detailed survey at ~ 2 m resolution required for the selection of future landing sites. Though only partial coverage of the moon is attained in the low orbits mandatory for high resolution, (see Appendix B) site survey could be coupled with mapping of regions that are of particular geophysical interest.

In all instances, TV imagery would be supplemented by the mapping of IR brightness by means of the IR mapper. Since thermal anomalies on the dark side near the sunrise terminator are most apparent, coverage of this region would be valuable. Use of the IR spectrometer appears to be of value only for the detection of transient gaseous emissions; this will be discussed later.

No lander would be carried in a pure orbital survey mission. As shown in Appendix A, a Titan III-C is sufficient to launch the Viking orbiter into a 100 km circular polar orbit around the moon and provides ample capability for orbital maneuvers. The SLV-3C vehicle could place the orbiter in this orbit, but would leave scant margin for maneuvers.

Real-time transmission of front-side data is required; the Viking recorder system would be used to store ~ 100 far-side pictures in each orbit.

c) Scientific Orbiter Mission

This type of mission requires some modifications of the 1975 Martian Viking orbiter payload. It is motivated by the wish to extend lunar exploration from orbit in those areas the instrumental payload of the Apollo CSM has shown to be valuable. Table 4 lists current CSM instrumentation. It may, for instance, be desirable to extend the use of the same remote sensors over a wider range of sun angles and latitudes than is available within the Apollo program. Alternatively, a need for further development of these instruments may be indicated, in order to obtain finer spatial resolution of observed differentiation, or to achieve enhanced sensitivity or a wider spectral range.

Table 4 - Apollo CSM Orbital Science Experiments

Material Properties

- x-ray spectrometer
- γ -ray spectrometer
- α -particle spectrometer
- EM sounder

Gravity

- S-band transponder

Atmosphere

- Mass spectrometer
- Far UV spectrometer

Thermal

- IR radiometer

Particles and Fields Environment

- Subsatellite (magnetometer, charged particles)

Integration of some CSM instruments into the current orbiter may be feasible. Others, with greater weight and power consumption than can currently be accommodated under minimum modifications, will require a completely redesigned orbiter. No lander is required for this mission.

For this mission a polar orbit at low altitude will be desired. The low altitude improves the spatial resolution available with a given sensor, may permit more ready detection of sources of a lunar atmosphere, and produces greater orbital perturbations due to gravity anomalies. As Appendix A indicates, even an orbiter with its weight increased from the present ~1400 lbs (without tanks) to ~3650 lbs could be launched into the required orbit by a Titan III-C.

Though it may appear that this type of mission compromises the objective of minimum modifications we have tried to adhere to, the prospects for development in the Mars Viking program should be borne in mind and the lunar program requirements should also be integrated into future advanced phases of Viking planning and design. These considerations apply also to some of the following sub-sections.

d) Far-Side Geophysical Observatory

In this type of mission and those described subsequently, both orbiter and lander are needed. While in all cases the lander scientific payload is fully utilized, the role of the orbiter varies from a primary task of data relay to dual use for both orbital science and data relay.

One objective of a far-side mission would be to utilize the far-side landings to set up parts of a network of geophysical observatories of the ALSEP type. The landed instrument package would typically contain a magnetometer, seismometer and charged particle detectors. The lifetime of such a landed station should be at least a year.

The orbiter function is primarily to provide a communication link to the far-side. Except for the orbiting magnetometer and solar wind spectrometer, the other orbital science is incidental for the purpose of this mission.

Thus, in this mission a higher altitude orbit is preferred. According to Appendix A a Titan III-D/Centaur could both carry one nominal Viking orbiter into a 600 km circular lunar orbit and emplace two "nominal" landers (as defined in Section 3) on two different surface sites.

The 600 km altitude is by no means desirable from the aspect of communications. Indeed, Appendix B demonstrates that a 5000 km circular equatorial orbit almost triples to 26% the fractional time that an orbiter can communicate with a site at 23° latitude such as Tsiolkovsky, compared to ~10% with a 600 km orbit. In either case, of course, communication with earth is possible for more than half of each orbit.

e) Far-Side Geochemical Mission

This mission aims at characterizing the features, processes and composition of the lunar far-side. The objective of the lander would be to make geological, geochemical and geophysical observations. The experiments would consist of TV cameras, mass spectrometer, x-ray diffractometer/spectrometer, magnetometer, seismometer and gravimeter. Some of the experiments form part of the Martian lander payloads, others would have to be adapted from their ALSEP prototypes.

The usefulness of the indicated measurements would be greatly furthered if the lander had a roving capability so that extensive regions could be explored. The Titan III-D/Centaur launch vehicle could, indeed, accommodate substantial lunar roving capability. A nominal orbiter could be launched into a circular lunar orbit at ~2000 km altitude, and a landed weight of ~2850 lbs (excluding tanks) could be placed on the surface, providing ~2000 lbs above the weight of the nominal lander, which could be applied to roving capability. The orbiter's primary function in this mission is as a communications link, but the return from the landed experiments would be greatly aided by remote sensing and imagery. Thus an altitude tradeoff between these two aspects may be necessary.

f) Polar Mission

This and the mission to follow envisions active scientific roles for both orbiter and lander.

An objective for an orbiter-lander combination would be to search for cold traps near the pole that might contain frozen volatiles either from a primitive lunar atmosphere or from continual out-gassing. The orbiter, with its imagery and an upgraded, actively cooled, IR radiometer, would search the poles for the coldest regions, presumably in the permanently shaded bottoms of craters. After the survey by the orbiter, a decision would be made for the landing site. The lander would contain at least a mass spectrometer-gas chromatograph and a sampling device (scoop and possibly a drill) for the detection of frozen volatiles. During this phase of the mission the orbiter must serve as a communication link since the polar lander will be out of sight of the earth.

The Titan III-D/Centaur provides ample capacity for this mission, including a substantial amount of orbiter fuel for maneuver. This may be desired to increase communication time, since, as shown in Appendix B, only a 6% fraction of the orbital period is available for communication in a 100 km circular polar orbit, which would be favored at least for the initial search phase of the mission.

g) Transient Event Mission

This type of mission, the most complex one dealt with in this report, makes dynamic use of both the lander and orbiter. It is clear from the background summary of Appendix C that the long lifetime of the Viking system offers a fair chance for its success.

The Viking orbiter with its nominal payload, TV camera, IR imager and IR spectrometer would, for a long period, scan the moon from an equatorial orbit in search for transient event. Dependent on the nature of the events, UV spectrometry and microwave mapping of surface temperatures could also be valuable. The location, nature, duration and intensity of transient events would be observed. From the pattern thus built up a decision would be made to commit the lander for ground truth observations of a particular event. The site and event would be chosen to maximize the probability that the lander be in the proximity of a lunar event in progress. If no sufficiently large events occur during the period of site selection, the lander would be set down at a site, probably in the Aristarchus region, to measure the effects produced by prior events and to await future activity. The lander itself would be similar to the Viking lander, carrying instrumentation for imaging, mass spectrometry, gas chromatography and ion detection. It is noteworthy that, notwithstanding the complexity of the mission, the present Viking orbiter and lander payload need only minimal modification.

Also, as shown in Appendix A, a satisfactory mission could be launched with either a Titan III-C/Centaur or a Titan III-D/Centaur. The need for a tradeoff between maximal observation time (higher orbits) and better instrument resolution is illustrated in Appendix B.

5. Summary and Discussion of Critical Issues

The preceding sections describe six classes of missions for which adaptation of the present Viking system appears prima facie desirable. These missions include excursions to sites beyond the planned access of the Apollo Program, including the poles and far-side locations. In this way, the missions may provide scientific knowledge about hitherto unexplored lunar regions or may alternatively aim at survey of future landing sites; they may extend the grid of geophysical observatories over most of the moon's surface. One class of missions described aims at investigating the enigmatic phenomenon of lunar transient events.

By bridging the prolonged gap between the termination of Apollo and the projected lunar program of the 1980's, the elements of a lunar missions program presented here can substantially advance NASA's avowed goal of balanced exploration of the entire solar system. By closing vital gaps in our knowledge of the moon, these program elements meet also the operational objective of widening the range of immediate options available to resumed manned lunar exploration in the 1980's. Moreover, on first sight, these elements appear also capable of blending into NASA's present program structure, being conceived as an extension and further utilization of the ongoing Viking program.

Though in the present study we have attempted to minimize the departure of systems from the present Viking design, it is the commonality between the proposed lunar missions and those presently designed for the Mars Viking that is at issue here: at what degree of disparity should the design and implementation of these missions be kept entirely separate?

Some precedents in NASA's history may guide us, at least qualitatively, to favor a common program:

- 1) the Mariner program has, basically under the same roof, accommodated missions to different planets, with different payloads and spacecraft, and weight increasing from the ~450 lbs of Mariner II to ~840 lbs of Mariners VI and VII.
- 2) the Mariner program has made flexible use of launch vehicles, changing from Atlas-Agena to Atlas Centaur, and similarly the projected Pioneer F will use an Atlas Centaur, whereas a Titan launch was planned for Pioneer G.
- 3) a certain degree of payload flexibility has been previously demonstrated both by the lunar Surveyor program and the ALSEP series, as well as by the Mariner program.

To obtain quantitative guidelines that could aid us in the present case, which involves all the above modes of differentiation combined, it will be necessary to estimate the cost increments incurred as a result of the departure of individual program elements from one set prototype. Though circumstances are different, it would then be possible and meaningful to compare these with expected costs of the necessary modifications of the Viking system for lunar exploration.

The major items that merit further in-depth technical and cost analysis emerge from the present study as follows:

- 1) What is the possible degree of commonality of the Viking lander in regard of both descent propulsion and scientific payload?
- 2) To what degree does the disparate mission profile with its pronounced solar irradiation cycling affect the thermal design of the Viking system?
- 3) How and at what price can the Viking orbiter-lander combination be interfaced with the different launch vehicles considered?
- 4) Discounting entirely new payload development, what is the technical feasibility and cost of integrating different, but off-the-shelf, experiments into the payload?
- 5) What are the problems with regard to the changes in the communication and data systems, including provision of a command link from earth to the lander via the orbiter?
- 6) What savings can be obtained in common development of roving capability for Mars and the moon?

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Attachments
Figures 1-3
Appendices A-C

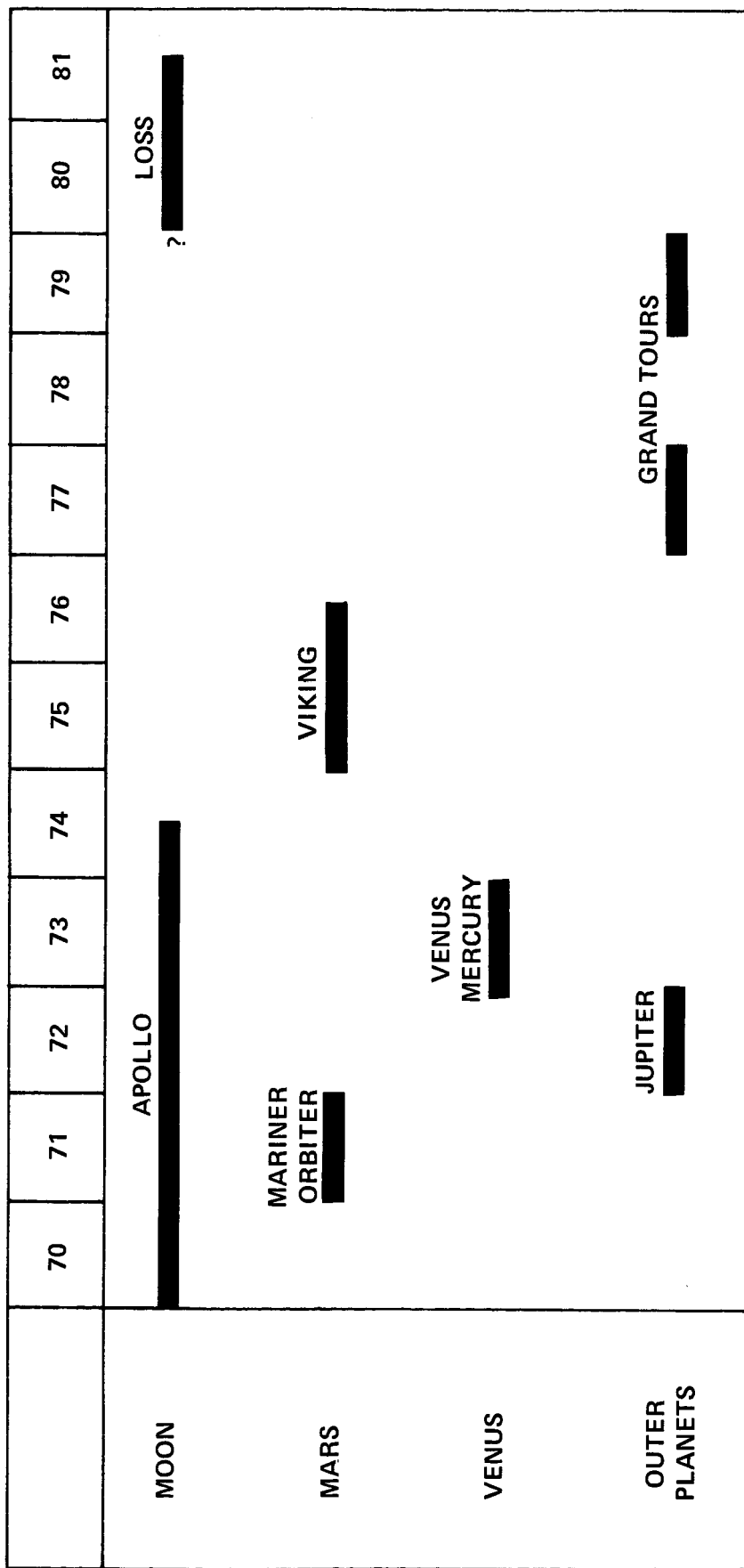


FIGURE 1 - NASA PLANETARY PROGRAM FOR THE 70's

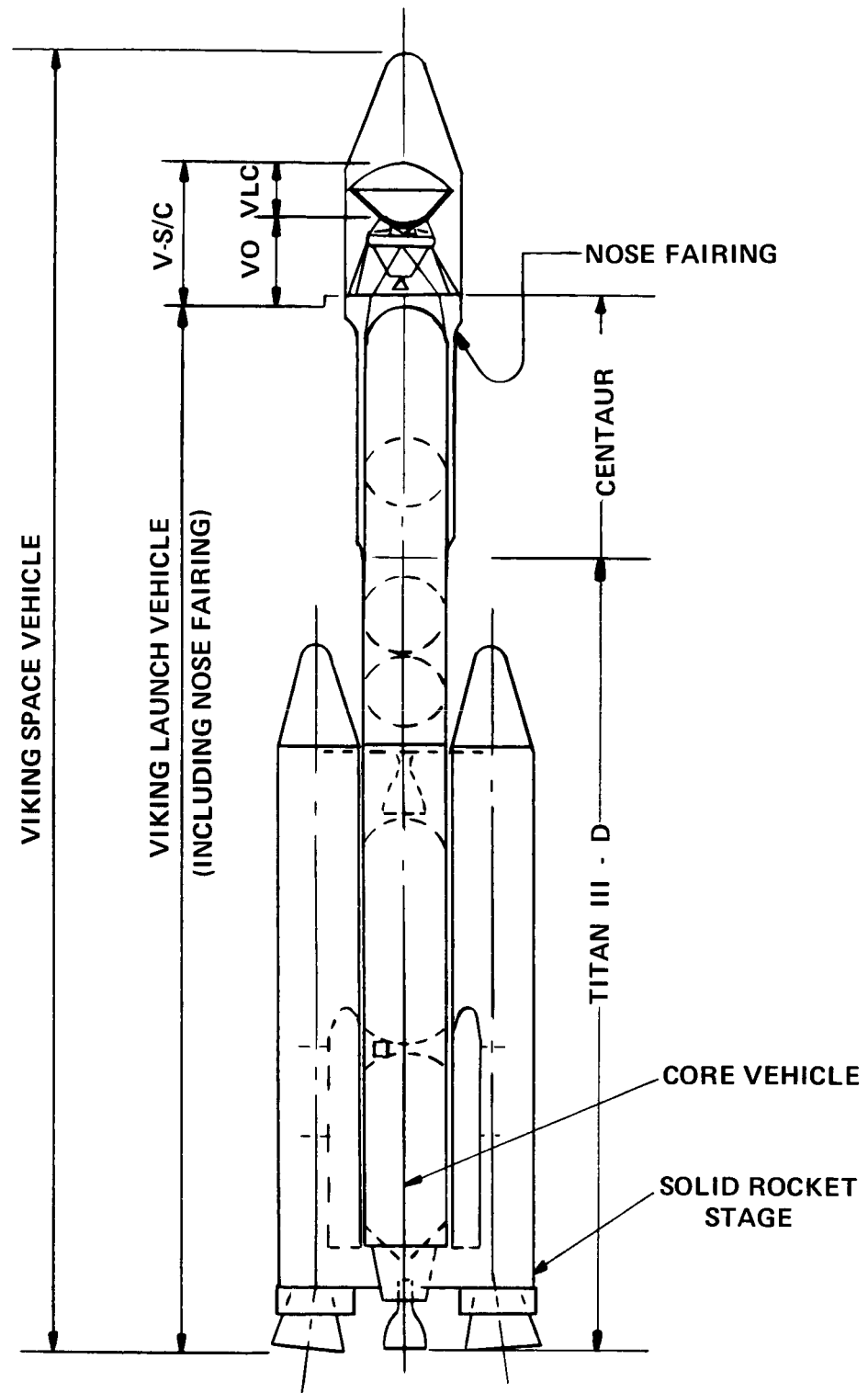


FIGURE 2 - SPACE VEHICLE CONFIGURATION

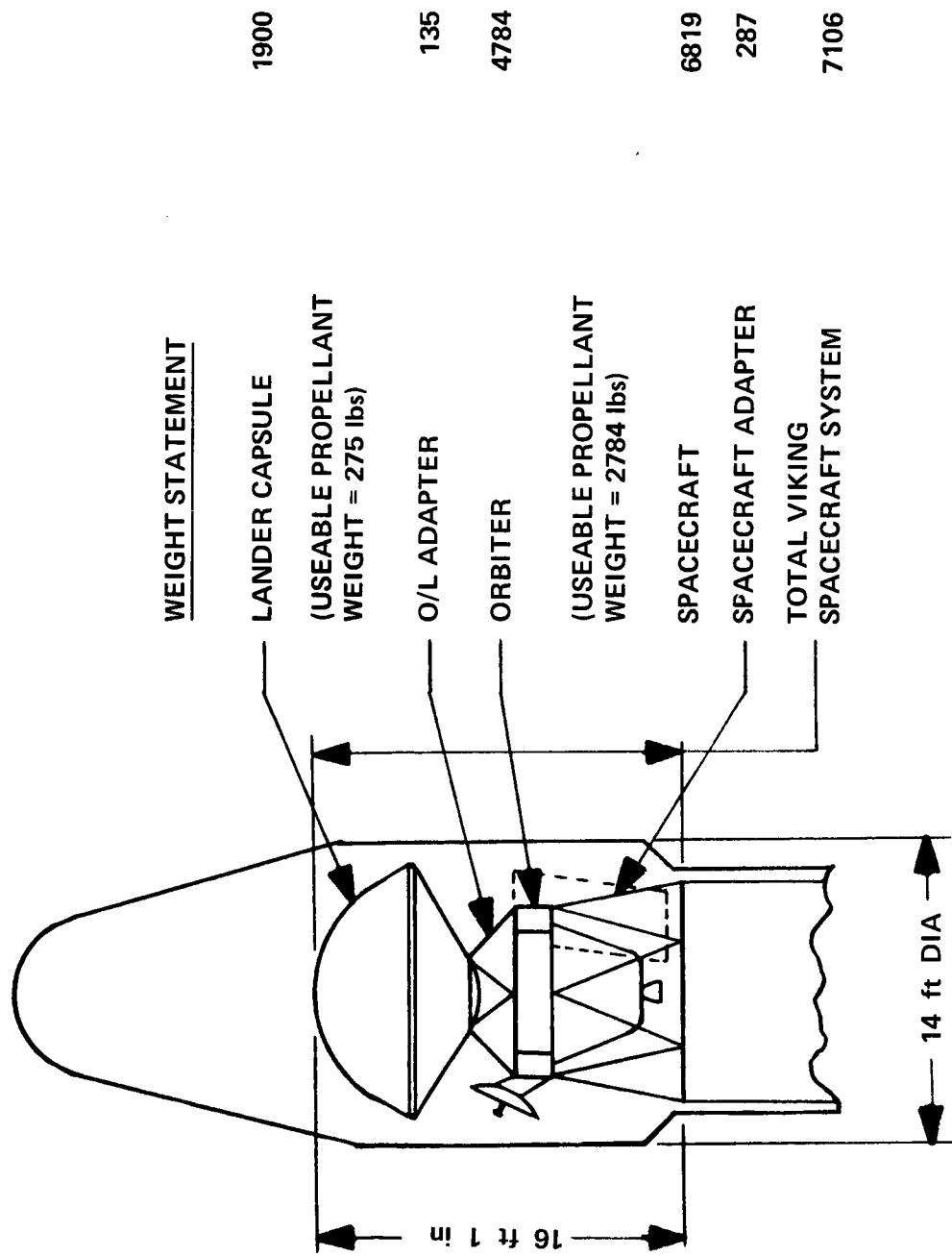


FIGURE 3 - PAYLOAD COMPARTMENT

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APPENDIX A

Propulsion and Launch Systems for Lunar Viking Missions

For a preliminary quantitative assessment of the consistency of propulsion requirements for the several types of missions discussed, with the capabilities of the Viking launch system or other suitable existing systems, a first order mission analysis has been performed. From the gamut of possible mission profiles associated with the differing options, typical profiles were chosen without any attempt at optimization; rather the profiles below illustrate the capability limits of the systems chosen. The ground rules and assumptions underlying this analysis are given in Table A1.

Table A1 - Ground Rules and Assumptions of Mission Analysis

TLI Weight Capacity Titan III-C	5,500 lbs
TLI Weight Capacity Titan III-D/Centaur	12,500 lbs
TLI Weight Capacity SLV IIIC	3,000 lbs
Nominal Viking Lander Weight (excl. tanks)	910 lbs
Liquid Rocket Motor and Tanks of Same	70 lbs
Fuel for Same	270 lbs
Nominal Viking Orbiter Weight (excl. tanks)	1,425 lbs
Liquid Rocket Motor and Tanks for Same	485 lbs
Fuel for Same	2,784 lbs
Orbiter-Lander Adapter	135 lbs
Mass Fraction, λ , Orbiter Motor	.85
Mass Fraction, λ , Lander Solid Rocket Motor	.85
Mass Fraction, λ , Lander Liquid Rocket Motor	.80

(i) Orbital Survey Mission:

1 nominal orbiter

Case a: Titan III-C, stretched tanks. Deliver 5500 lbs into TLI - deboost 4090 lbs into 1000 km circular polar orbit - deboost 3690 lbs into 100 km circular polar orbit: orbiter 1425 lbs, tanks 610 lbs, fuel 1655 lbs; orbiter ΔV capacity 5600 ft/sec.

Case b: Titan III-C, off-loaded, nominal tanks. 4700 lbs into TLI-deboost 3,500 lbs into 1000 km circular orbit - deboost 3158 lbs into 100 km circular orbit: orbiter 1425 lbs, tanks 485 lbs, fuel 1248 lbs; orbiter ΔV - 4670 ft/sec.

Case c: SLV III C (TLI capacity 3000 lbs) 2680 lbs into TLI-deboost 1910 lbs into 100 km circular polar orbit; orbiter 1425 lbs, tanks 485 lbs, no fuel; no orbiter ΔV .

(ii) Scientific Orbiter Mission:

1 enlarged orbiter

Titan III-C, stretched tanks. 5500 lbs into TLI - deboost 3930 lbs into 100 km circular polar orbit: orbiter 3650 lbs, tanks 280 lbs, no fuel, no orbiter ΔV .

(iii) Far-Side Geophysical Observatory

2 nominal landers, 1 nominal orbiter

Titan III-D Centaur. 10350 lbs into TLI - use orbiter engine and 2800 lbs fuel to place orbiter + 2 landers into 600 km circular equatorial orbit. - deboost landers to surface (2800 lbs fuel/lander).

(iv) Far-Side Geochemical Mission

1 enlarged lander

nominal orbiter, slightly stretched tanks

Titan III-D/Centaur. 12500 lbs into TLI - use orbiter engine and 2970 lbs fuel to deboost orbiter - lander system into 2000 km circular equatorial orbit - then deboost lander to far-side surface as follows: with liquid fuel engine + 510 lbs fuel into 2000 km x 100 km ellipse, 500 lbs fuel into 100 km circular orbit, then to surface with 50 lbs liquid fuel and 2700 lbs solid fuel. Final surface weight 3365 lbs.

(v) Polar Mission

Nominal lander, enlarged orbiter

Titan III-D/Centaur. 12500 lbs into TLI - use orbiter engine - 3570 lbs fuel to deboost orbiter - lander to surface near pole. Final weight in orbit (including 135 lbs adapter and 630 lbs tanks): 6325 lbs.

(vi) Transient Event Mission

Nominal lander, nominal basic orbiter with stretched tanks

Case a: Titan III-D/Centaur. 12500 lbs into TLI - use orbiter engine + 3360 lbs fuel to deboost orbiter - lander into 600 km circular equatorial orbit - use 1740 lbs fuel to rotate orbit by 23° - Use 240 lbs fuel to deboost into 100 km x 600 km ellipse - use 1300 lbs fuel to deboost lander to surface - using 250 lbs fuel boost orbiter into 100 x 2000 km ellipse; remaining orbiter fuel 1430 lbs, ΔV 4040 ft/sec.

Case b: Titan III-D/Centaur, off-loaded and nominal lander. 7720 lbs into TLI. - using 2090 lbs fuel deboost lander - orbiter into 600 km circular equatorial orbit - separate lander and using 150 lbs liquid fuel rotate plane by 23°, deboost lander into 0 km x 600 km ellipse. - using 1220 lbs solid fuel deboost lander to surface.

APPENDIX B

Orbital Constraints on Surface Observation
and Communication with Surface Site

1. General Considerations

The results, given in this appendix, that pertain to TV imagery from orbit, are based on the camera system specifications of Section 3. In addition, since the exposure time has not been finally determined (see Section 3), the following three values were adopted for the present analysis: .3 ms, 1 ms, 3 ms. Pictures are considered as blurred if the spacecraft travels a distance $> .3$ resolution elements during exposure. The specifications impose certain constraints on orbital parameters, on communications, and on mission profiles.

a. Altitudes for unblurred pictures:

For the three exposure times given, the least circular altitudes for unblurred pictures are:

Exposure Time (msec)	Altitude (km)
.3	90
1	260
3	612

b. Resolution

The resolution corresponding to given altitude and elevation angle is shown in Figure B1.

With a least altitude of 90 km, the best possible resolution is ~ 1.5 m.

2. Orbital Survey Missions

In this section, the conditions for extensive photographic coverage of the moon are examined.

The conditions for overlapping swaths are shown in Figure B2. For the given camera, with a half-angle $1/2^\circ$, it is possible to take 6 pictures transverse to the ground track, giving an effective half-angle of 3° , at an altitude above 460 km. The resolution is 8 m.

With this configuration complete coverage is possible in one month, and complete coverage at practically all illumination conditions would take no more than one year.

At lower altitudes it is not possible to obtain overlapping ground tracks, nor can it be guaranteed that the ground tracks on successive months will cover the entire lunar surface. However, by pointing the camera accurately, it is possible to cover the entire moon in two months from an altitude of 333 km; resolution ~ 6 m. Very little improvement in resolution is possible by accepting longer coverage times.

At altitudes above 665 km, it is possible to photograph the lunar surface twice in one month, allowing stereo coverage at a resolution ~ 12 m.

It appears, therefore, that the Viking orbiter TV system is not ideally matched to extension of medium resolution (30-90 m) photographic coverage over the whole moon, and is not capable at all of providing complete coverage at ~ 1 m resolution. It is best suited to high resolution (10-15 m) coverage, which can be completed within one month.

3. Transient Event Mission

Fifty per cent of recorded transient events have occurred in Aristarchus. A mission designed to detect and study such events will therefore be focused on Aristarchus. The following specifications are assumed:

- a. to observe Aristarchus for as long a time as possible
- b. low altitude for high resolution
- c. the line of sight to Aristarchus must be $\geq 10^\circ$ above the horizon
- d. the camera may not point more than 110° from the sun-moon direction
- e. the system does not operate when eclipsed by the moon

The lowest circular orbits from which Aristarchus can be observed at each pass are equatorial. The lowest possible altitude for a 10° line of sight is 300 km, but a considerably higher altitude is necessary for long observation times. Figure B3 shows the percentage of time in any month, during which Aristarchus is observable, under the constraints mentioned above. Some tradeoff between observation time and resolution is clearly called for: an upper limit on the required resolution should be defined.

4. Polar Mission

A lander is assumed to be in the vicinity of the pole, the orbiter in circular polar orbit. An elevation of 10° is assumed necessary for lander-to-orbiter communications. Figure B3a shows the proportion of the time during which communications are possible. Again, a tradeoff between resolution and communications time is necessary.

5. Far-Side Mission

The essential requirement here is for the orbiter to maintain communications contact with the lander and relay the data to earth. Communication with earth is possible for more than half of each orbit. Communication with the lander is subject to the same restrictions outlined in Section 2, and, for a site at the same latitude as Aristarchus, (e.g., Tsiolkovsky) will lead to identical results.

If the requirement for good resolution is relaxed in favor of longer communication time, higher altitudes are possible. The effect of this on communication time is shown in Figure B3b. Beyond about 5000 km there is little improvement in time. Resolution at this altitude is about 85 m.

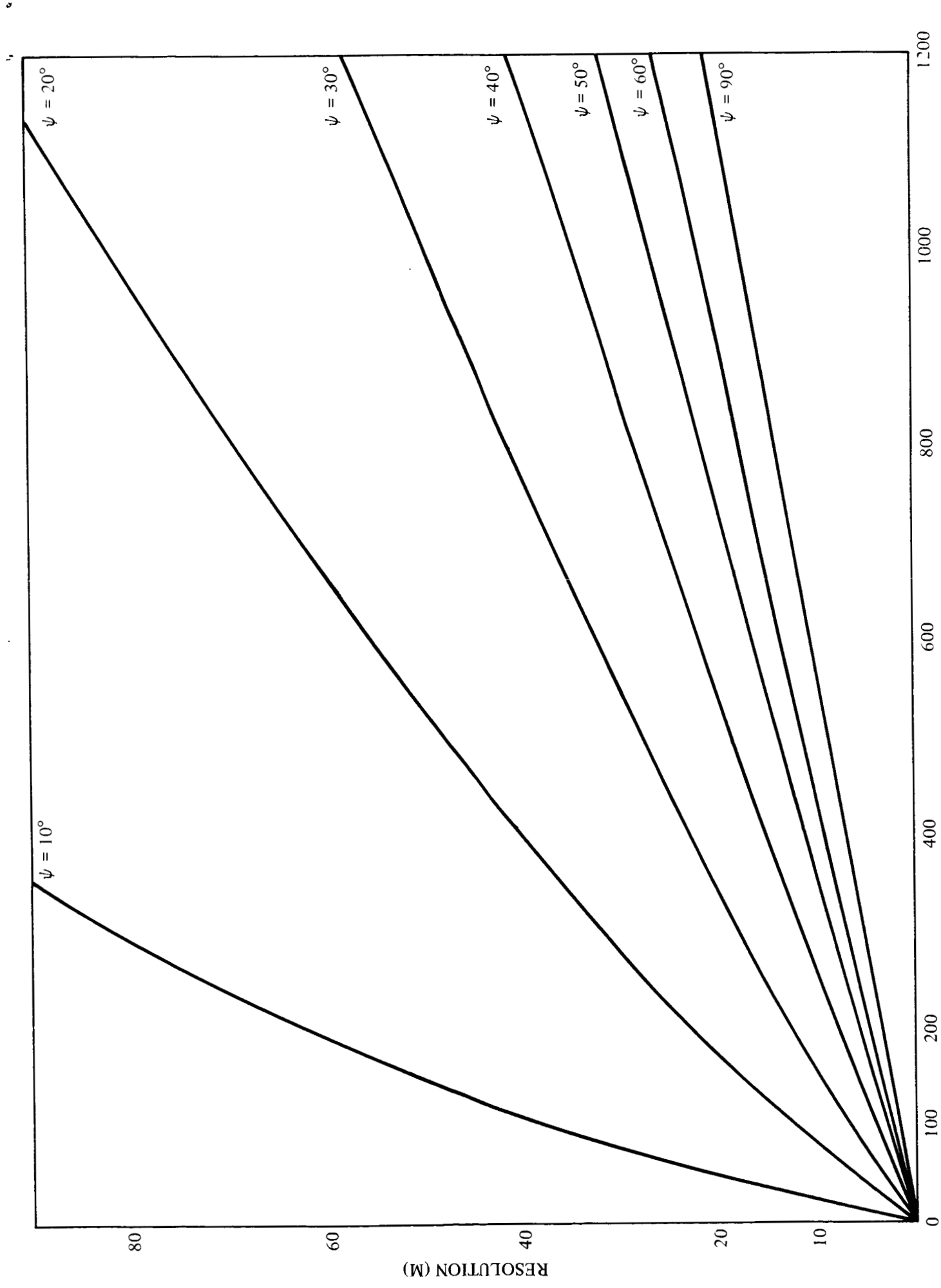


FIGURE B1 - RESOLUTION VS ALTITUDE AND ELEVATION ANGLE

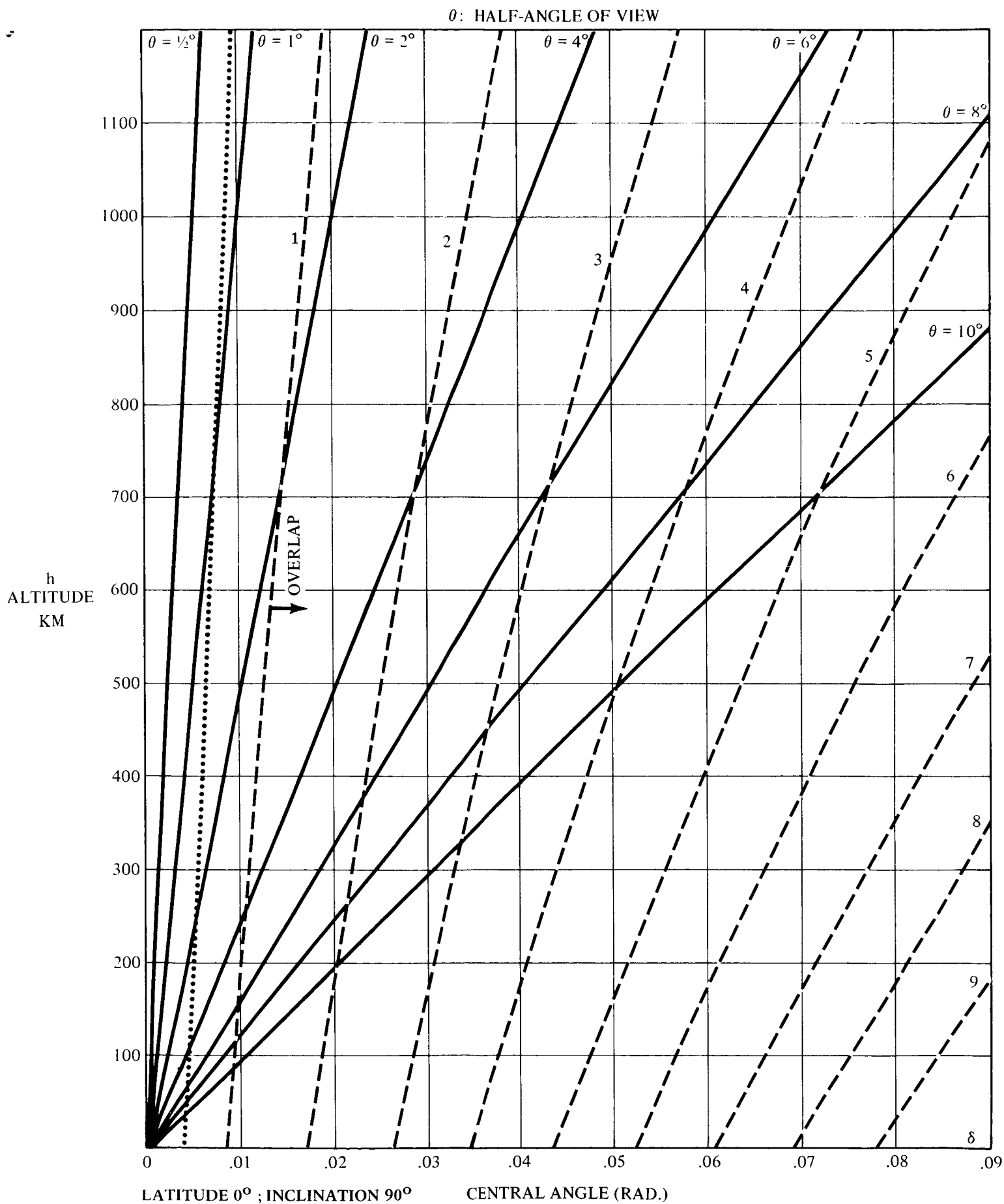


FIGURE B2 - NUMBER OF SUCCESSIVE PASSES VIEWING SAME SITE

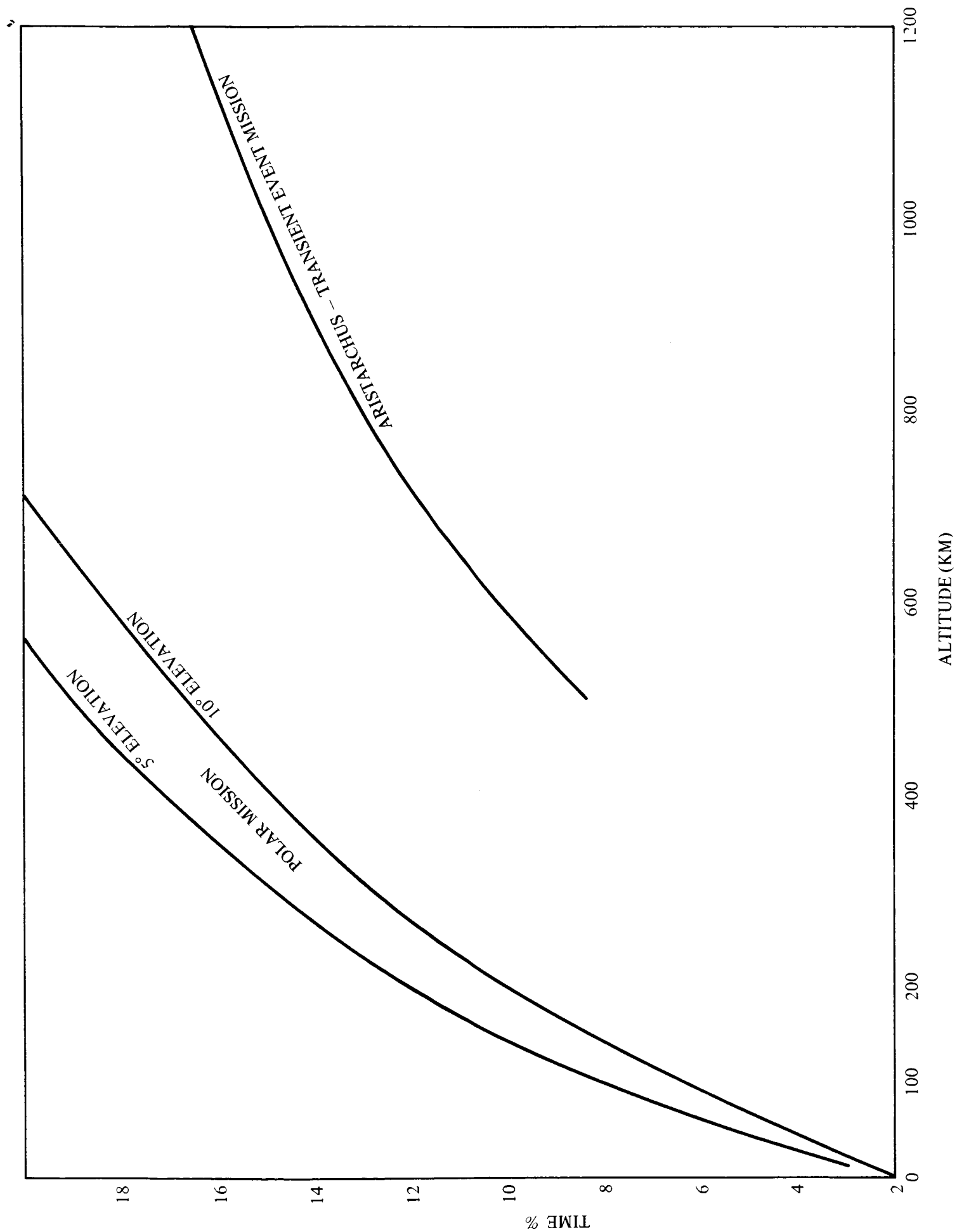


FIGURE B3a: PROPORTION OF TIME DURING WHICH SITE CAN BE OBSERVED

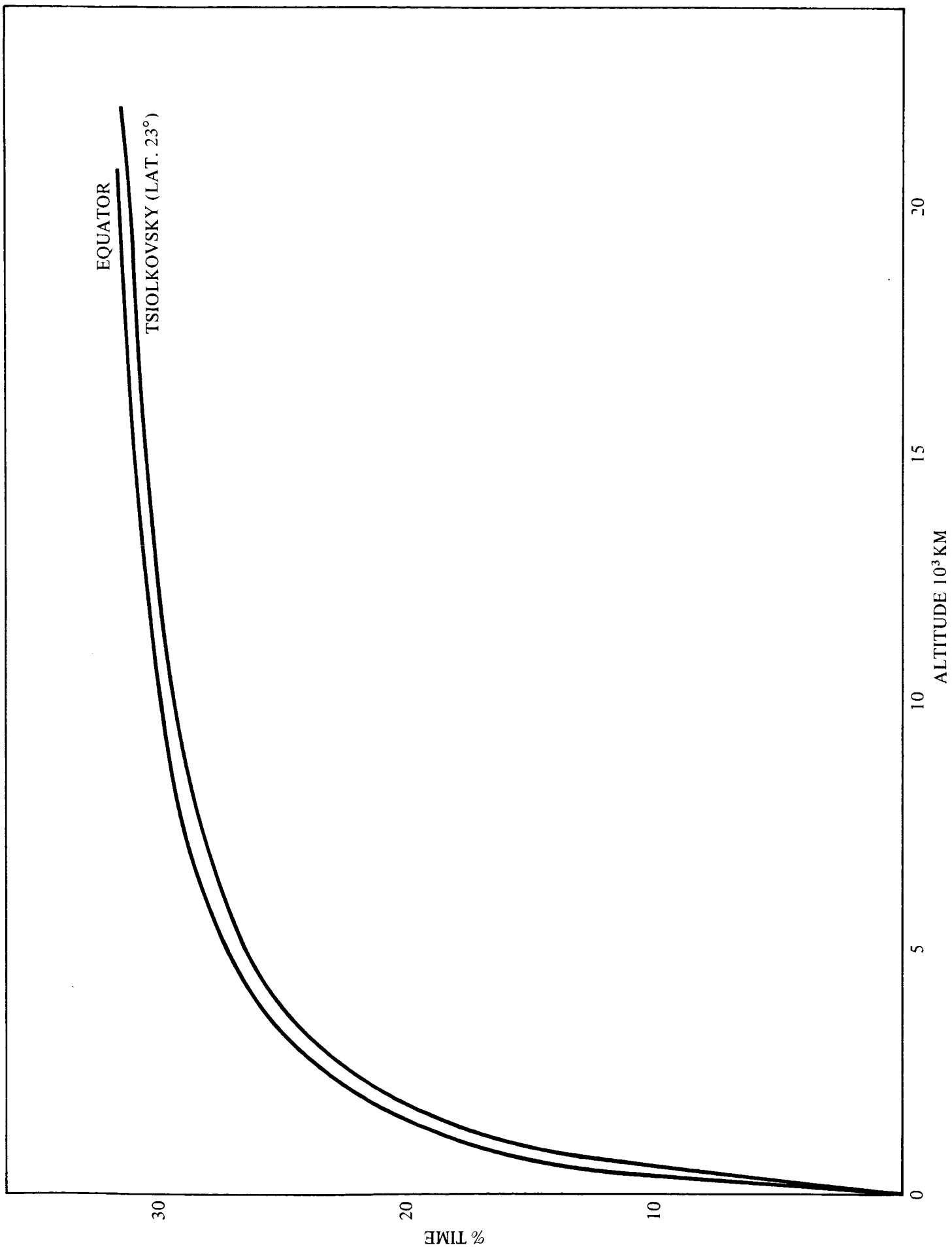


FIGURE B3b - PROPORTION OF TIME SITE CAN BE OBSERVED

APPENDIX C

Lunar Transient Events

The occurrence of numerous so-called lunar transient events has been reported over the last two centuries. The events are characterized by color changes, brightenings, bright starlike spots, obscuration of the surface, appearance of spectral bands and IR anomalies. The characteristic sites of these events are in bright-rayed craters, dark-floored craters, at maria edges. As viewed from earth, the reported events lasted up to four hours, with an average of 20 minutes.

In the present century, 210 events have been observed, while about 2 events per month were reported during the operation "Moonblink" from 8/26/64 to 4/1/66. It is possible that some events are spurious, the effects being produced perhaps by the earth's atmosphere. However, at least some of the events reported have been confirmed by simultaneous observations from different sites on earth that were carried out by observers noted for their carefulness and reliability.

Of all the events, about 50% arose in the Aristarchus uplift region, which includes Schröters Valley and Cobrahead. It should be noted that no Apollo landings are scheduled in this area.

A number of explanations have been suggested for the events. Hypotheses have been made concerning thermoluminescence and excitation by solar radiation and plasma. Laboratory experiments, however, appear to indicate a discrepancy of several orders of magnitude between observed lunar brightening and measured luminescence. It appears that tidal influences have importance, with correlation of maximum event probability and lunar perigee, and a subsidiary maximum present at apogee. Lunar tides are about 100 times as strong as those on earth; it is possible, then, that induced stresses may be significant in producing the transient events, perhaps facilitating efflux of gases or volcanic material. Such effluxes would be important for the determination of the composition and evolution of the lunar interior.

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